APPLICATION NO. 09/826,117

TITLE OF INVENTION: Hyhrid Walsh Codes for CDMA

INVENTOR: Urbain A. von der Embse

Marked up version of SUBSTITUTE SPECIFICATION using the specification of 2001.

APPLICATION NO. 09/826,117

TITLE OF INVENTION: Hybrid ~~Complex~~ Walsh Codes for CDMA

INVENTOR~~S~~: Urbain Alfred von der Embse

BACKGROUND OF THE INVENTION

I. Field of the Invention

~~**TECHNICAL FIELD**~~

The present invention relates to CDMA (Code Division Multiple Access) cellular telephone and wireless data communications with data rates up to multiple T1 (1.544 Mbps) and higher (>100 Mbps), and to optical CDMA with data rates in the Gbps and higher ranges. Applications are mobile, point-to-point and satellite communication networks. More specifically the present invention relates to novel ~~complex and h~~hybrid complex Walsh codes developed to replace current real Walsh orthogonal CDMA channelization codes.

~~**CONTENTS**~~

II. Description of the Related Art

~~**BACKGROUND ART**~~

~~Current~~ CDMA art is represented ~~art is represented~~ by the recent work on multiple access for broadband wireless communications which includes ~~communications, the G3 (third generation CDMA) proposed standard candidates, the current IS-95 CDMA standard, the early Qualcomm patents, and the real Walsh technology. These are documented in references 1,2,3,4,5,6. Reference 1 is an issue of the IEEE communications magazine devoted to multiple access communications for broadband wireless networks, reference 2 is an issue on IEEE personal communications devoted to the third generation (3G) mobile systems in Europe~~"Multiple Access for Broadband Networks", IEEE Communications magazine July 2000 Vol. 38 No. 7, "Third Generation Mobile Systems in Europe", IEEE Personal Communications April 1998 Vol. 5 No. 2 ~~reference 3 is the~~ ,IS-95/IS-95A, ~~standard primarily developed by Qualcomm, references 4 and 5 are Qualcomm patents addressing the use of real Walsh orthogonal CDMA codes, and reference 6 is the widely used reference on real Walsh technology.~~ , the IS-95/IS-95A, the 3G CDMA2000 and W-CDMA, and the listed patents.

~~Current art using real Walsh orthogonal CDMA channelization codes is represented by the scenario described in the following with the aid of equations (1) and FIG 1,2,3,4. This scenario considers CDMA communications spread over a common frequency band for each of the communication channels. These CDMA communications channels for each of the users are defined by assigning a unique Walsh orthogonal spreading codes to each user. The Walsh code for each user spreads the user data symbols over the common frequency band. These Walsh encoded user signals are summed and re-spread over the same frequency band by one or more PN codes, to generate the CDMA communications signal which is modulated and transmitted. The communications link consists of a transmitter, propagation path, and receiver, as well as interfaces and control.~~

~~It is assumed that the communication link is in the communications mode with all of the users communicating at the same symbol rate and the synchronization is sufficiently accurate and robust to support this communications mode. In addition, the possible power differences between the users is assumed to be incorporated in the data symbol amplitudes prior to the CDMA encoding in the CDMA transmitter, and the power is uniformly spread over the wideband by proper selection of the CDMA pulse waveform. It is self evident to anyone skilled in the CDMA communications art that these communications mode assumptions are both reasonable and representative of the current CDMA art and do not limit the applicability of this invention.~~

~~Transmitter equations **(1)** describe a representative real Walsh CDMA encoding for the transmitter in FIG. **1**. It is assumed that there are N Walsh code vectors W(u) each of length N chips **1**. The code vector is presented by a 1xN N-chip row vector W(u)=[W(u,1),…,W(u,N)] where W(u,n) is chip n of code u. The code vectors are the row vectors of the Walsh matrix W. Walsh code chip n of code vector u has the possible values W(u,n)= +/-1. Each user is assigned a unique Walsh code which allows the code vectors to be designated by the user symbols u=0,1,…,N-1 for N Walsh codes. User data symbols **2** are the set of complex symbols {Z(u), u=0,,1,…,N-1} and the set of real symbols {R(~~u_R~~), I(~~U_I~~), ~~u_R~~, ~~u_I~~ =0,1,…,N-1} where Z is a complex symbol and R,I are real symbols assigned to the real, imaginary communications axis. Examples of complex user symbols are QPSK and OQPSK encoded data corresponding to 4-phase and offset 4-phase symbol coding. Examples of real user symbols are PSK and DPSK encoded data corresponding to 2-phase and differential 2-phase symbol coding. Although not considered in this example, it is possible to use combinations of both complex and real data symbols.~~

~~Current real Walsh CDMA encoding for transmitter **(1)**~~

~~1 Walsh codes~~

~~W = Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors~~

~~= [W(u)] matrix of row vectors W(u)~~

~~= [W(u,n)] matrix of elements W(u,n)~~

~~W(u) = Walsh code vector u for u=0,1,…,N-1~~

~~= [W(u,0), W(u,1), …, W(u,N-1)]~~

~~= 1xN row vector of chips W(u,0),….,W(u,N-1)~~

~~W(u,n) = Walsh code u chip n~~

~~= +/+1 possible values~~

~~2 Data symbols~~

~~Z(u) = Complex data symbol for user u~~

~~R(u_R) = Real data symbol for user u_R assigned to the Real axis of the CDMA signal~~

~~I(u_I) = Real data symbol for user u_I assigned to the Imaginary axis of the CDMA signal~~

~~3 Walsh encoded data~~

~~Complex data symbols~~

~~Z(u,n) = Z(u) sgn{ W(u,n)}~~

~~= User u chip n Walsh encoded complex data~~

~~Real data symbols~~

~~R(u_R,n) = R(u_R) sgn{ W(u_R,n) }~~

~~= User u_R chip n Walsh encoded real data~~

~~I(u_I,n) = R(u_R) sgn{ W(u_R,n) }~~

~~= User u_I chip n Walsh encoded real data~~

~~where sgn{ (o) } = Algeraic sign of "(o)"~~

~~4PN scrambling~~

~~$P_R(n)$ = Chip n of PN codes for real axis~~

~~$P_I(n)$ = Chip n of PN codes for imaginary Axis~~

~~Complex data symbols:~~

~~$Z(n)$ = PN scrambled real Walsh encoded data chips after summing over the users~~

~~$$= \sum_{u} Z(u,n) P_2(n) [P_R(n) + j P_I(n)]$$~~

~~$$= \sum_{u} Z(u,n) \text{sign}\{P_2(n)\} [\text{sign}\{P_R(n)\} + j\, \text{sign}\{P_I(n)\}]$$~~

~~= Real Walsh CDMA encoded complex chips~~

~~data symbols:~~

~~$Z(n)$ =~~

~~$$[\sum_{u_R} R(u_R,n)) + j \sum_{u_I} I(u_I,n)\ ][\text{sign}\{P_R(n)\} + j\ \text{sign}\{P_I(n)\}]$$~~

~~= Real Walsh CDMA encoded real chips~~

~~User data is encoded by the Walsh CDMA codes **3**. Each of the user symbols $Z(u)$, $R(u_R)$, $I(u_I)$ is assigned a unique Walsh code. $W(u)$, $W(u_R)$, $W(u_I)$. Walsh encoding of each user data symbol generates an N-chip sequence with each chip in the sequence consisting of the user data symbol with the sign of the corresponding Walsh code chip, which means each chip = [Data symbol] x [Sign of Walsh chip].~~

~~The Walsh encoded data symbols are summed and encoded with PN codes **4**. These PN codes are 2-phase with each chip equal to +/-1 which means PN encoding consists of sign changes with each sign change corresponding to the sign of the PN chip. Encoding~~

~~with PN means each chip of the summed Walsh encoded data symbols has a sign change when the corresponding PN chip is -1, and remains unchanged for +1 values. This operation is described by a multiplication of each chip of the summed Walsh encoded data symbols with the sign of the PN chip. Purpose of the PN encoding for complex data symbols is to provide scrambling of the summed Walsh encoded data symbols as well as isolation between groups of users. Purpose of the separate PN encoding for the real and imaginary axes is to provide approximate orthogonality between the real and imaginary axes, since the same Walsh orthogonal codes are being used for these axes. Another PN encoding can be used as illustrated in these equations for the combined real and imaginary CDMA signals to provide scrambline and isolation between groups of users.~~

~~Receiver equations **(2)** describe a representative real Walsh CDMA decoding for the receiver in FIG. **3**. The receiver front end **5** provides estimates $\{\hat{Z}(n)=\hat{R}(n)+j\,\hat{I}(n)\}$ of the transmitted real Walsh CDMA encoded chips $\{Z(n)=R(n)+jI(n)\}$ for the complex and real data symbols. Orthogonality property **6** is expressed as a matrix product of the real Walsh code chips or equivalently as a matrix produce of the Walsh code chip numerical signs. The 2-phase PN codes **7** have the useful decoding property that the square of each code chip is unity which is equivalent to observing that the square of each code chip numerical sign is unity. Decoding algorithms **8** perform the inverse of the signal processing for the encoding in equations (1) to recover estimates $\{\hat{Z}(u)\}$ or $\{\hat{R}(u_R),\ \hat{I}(u_I)\}$ of the transmitter user symbols $\{Z(u)\}$ or $\{R(u_R),\ I(u_I)\}$ for the respective complex or real data symbols.~~

~~Current real Walsh CDMA decoding for receiver (2)~~

~~5 Receiver front end provides estimates~~ ~~$\{\hat{Z}(n) = \hat{R}(n) + j\hat{I}(n)\}$~~

~~of the encoded transmitter chip symbols~~ ~~$\{Z(n)=R(n)+jI(n)\}$~~

~~for the complex and real data symbols~~

~~6Orthogonality property of real Walsh NxN matrix W~~

~~$$\sum_n W(\hat{u},n)W(n,u) = \sum_n \text{sign}\{W(\hat{u},n)\}\,\text{sign}\{W(n,u)\}$$~~

~~$$= N\ \delta(\hat{u},u)$$~~

~~where $\delta(\hat{u},u)$ = Delta function of $\hat{u}$ and u~~

~~$= 1$ for $\hat{u}=u$~~

~~$= 0$ otherwise~~

~~7PN decoding property~~

~~$$P_2(n)P_2(n) = \text{sgn}\{P_2(n)\}\ \text{sgn}\{P_2(n)\}$$~~

~~$$= 1$$~~

~~8Decoding algorithm~~

~~Complex data symbols~~

$$\cancel{\hat{Z}(u)}$$

$$\cancel{N^{-1} \sum_n \hat{Z}(n)[\text{sign}\{P_2(n)\}\ [\text{sign}\{P_R(n)\} - j\,\text{sign}\{P_I(n)\}]\ \text{sign}\{W(n,u)\}}}$$

~~= Receiver estimate of the transmitted complex data symbol Z(u)~~

~~Real data symbols~~

$$\cancel{\hat{R}(u_R) =}$$

$$\cancel{\text{Real}[\ N^{-1} \sum_n \hat{Z}(n)[\text{sgn}\{P_R(n)\} - j\,\text{sgn}\{P_I(n)\}]\ \text{sgn}\{P_2(n)\}\text{sgn}\{W(n,u_R)\}\ ]}$$

~~= Receiver estimate of the transmitted complex data symbol~~ ~~$R(u_R)$~~

$$\cancel{\hat{I}(u_I) =}$$

$$\cancel{\text{Imag}[\ N^{-1} \sum_n \hat{Z}(n)[\text{sgn}\{P_R(n)\} - j\,\text{sgn}\{P_I(n)\}]\ \text{sgn}\{P_2(n)\}\text{sgn}\{W(n,u_I)\}\ ]}$$

~~= Receiver estimate of the transmitted complex data symbol~~ ~~$I(u_I)$~~

~~FIG. **1** CDMA transmitter block diagram is representative of a current CDMA transmitter which includes an implementation of the current real Walsh CDMA channelization encoding in equations **(1)**. This block diagram becomes a representative implementation of the CDMA transmitter which implements the new complex Walsh CDMA encoding when the current real Walsh CDMA encoding **13** is replaced by the new complex Walsh CDMA encoding of this invention. Signal processing starts with the stream of user input data words **9**. Frame processor **10** accepts these data words and performs the encoding and frame formatting, and passes the outputs to the symbol encoder **11** which encodes the frame symbols into amplitude and phase coded symbols **12** which could be complex {Z(u)} or real {R(u~~~~$_R$~~~~), I(u~~~~$_I$~~~~)} depending on the application. These symbols **12** are the inputs to the current real Walsh CDMA encoding in equations **(1)**. Inputs {Z(u)}, {R(u~~~~$_R$~~~~), I(u~~~~$_I$~~~~)} **12** are real Walsh encoded, summed over the users, and~~

~~scrambled by PN in the current real Walsh CDMA encoder **13** to generate the complex output chips {Z(n)} **14**. This encoding **13** is a representative implementation of equations **(1)**. These output chips Z(n) are waveform modulated **15** to generate the analog complex signal z(t) which is single sideband upconverted, amplified, and transmitted (Tx) by the analog front end of the transmitter **15** as the real waveform v(t) **16** at the carrier frequency f_0 whose amplitude is the real part of the complex envelope of the baseband waveform z(t) multiplied by the carrier frequency and the phase angle ϕ accounts for the phase change from the baseband signal to the transmitted signal.~~

FIG. **1** is a representative wireless cellular communication network application of the CDMA trasmitter in FIG. **2**. FIG. **1** is a schematic layout of part of a CDMA network which depicts cells **101,102,103,104** that partition this portion of the area coverage of the network, depicts one of the users **105** located within a cell with forward and reverse communications links **106** with the cell-site base station **107**, depicts the base station communication links **108** with the MSC/WSC **109**, and depicts the MSC/WSC communication links with another base station **117**, with another MSC/WSC **116**, and with external elements **110,111,112,113,114,115**. One or more base stations are assigned to each cell or multiple cells or sectors of cells depending on the application. One of the base stations **109** in the network serves as the MSC (mobile switching center) or WSC (wireless switching center) which is the network system controller and switching and routing center that controls all of user timing, synchronization, and traffic in the network and with all external interfaces, including other MSC's. External interfaces could include satellite **110**, PSTN (public switched telephone network) **111**, LAN (local area network) **112**, PAN (personal area network) **113**, UWB (ultra-wideband network) **114**, and optical networks **115**. As illustrated in the figure, base station **107** is the nominal

cell-site station for cells i-2, i-1, i, i+1 identified as **101,102,102,104**, which means it is intended to service these cells with overlapping coverage from other base stations. The cell topology and coverage depicted in the figure are intended to be illustrative.

Fig. **2** depicts a representative embodiment of the CDMA transmitter signal processing in FIG. **1** for the forward and reverse CDMA links **106** between the base station and the users for CDMA2000 and W-CDMA that implements the CDMA coding for synchronization, real Walsh channelization, and scrambling of the data for transmission. CDMA2000 and W-CDMA use real Walsh codes **120** for channelization of the data. which can be expressed in layered format which progresses from the highest data rate for the shortest codes to the lowest data rate for the longest codes in a format referred to as OVSF (orthogonal fixed spreading factor) codes. OVSF implementation of real Walsh codes **120** supports a variable data rate with variable length real Walsh codes over a fixed transmission channel. This invention disclosure will use fixed length codes which implement OVSF by assigning more code vectors to the higher data rate users. Data inputs **112** in FIG. **1A** to the transmitter CDMA signal processing are the inphase data symbols $R(u_R)$ **118** and quadrature data symbols $I(u_I)$ **119** of the complex data symbols $Z(u)=R(u_R)+j\ I(u_I)$ from the block interleaving processing in the transmitter. A real Walsh code **120** ranging in length from N=4 to N=512 chips spreads and channelizes the data by encoding **121** the inphase and quadrature data symbols with rate R=N codes corresponding to the channel assignments of the data chips. A long PN code **122** encodes the inphase and quadrature real Walsh encoded chips **123** with a 0,1 binary code. Encoding is a (+/-) sign change to the chip symbols corresponding to the 0,1 code value. Long code characteristics have the PN property with quasi-orthogonal auto-correlations and cross-correlations. This long PN code covering of the real Walsh encoded chips is followed by a short complex

PN code covering in **124,125,126.** This complex PN short code encodes the inphase and quadrature chips with a complex multiply operation **126.** Outputs are inphase and quadrature components of the complex chips which have been rate R=1 phase coded with both the long and short PN codes. Low pass filtering (LPF), summation (Σ) over the Walsh channels for each chip symbol, modulation of the chip symbols to generate a digital waveform, and digital-to-analog (D/A) conversion operations **127** are performed on these encoded inphase and quadrature chip symbols to generate the analog inphase x(t) signal **128** and the quadrature y(t) signal **129** which are the components of the complex signal z(t)=x(t)+jy(t) where $j=\sqrt{-1}$. This complex signal z(t) is single-sideband up-converted to an IF frequency and then up-converted by the RF frequency front end to the RF signal v(t) **133.** Single sideband up-conversion of the baseband signal is performed by multiplication of the inphase signal x(t) with the cosine of the carrier frequency f_0 **130** and the quadrature signal y(t) by the sine of the carrier frequency **131** which is a 90 degree phase shifted version of the carrier frequency, and summing **132** to generate the real signal v(t) **133.**

~~It should be obvious to anyone skilled in the communications art that this example implementation in FIG. 1 clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.~~

~~FIG. 2 real Walsh CDMA encoding is a representative implementation of the real Walsh CDMA encoding 13 in FIG. 1 and in equations (1). Inputs are the user data symbols which could be complex {Z(u)} or real {R(u_R) + jI(u_I)} 17. For complex and real data symbols the encoding of each user by the corresponding~~

~~Walsh code is described in **18** by the implementation of transferring the sign of each Walsh code chip to the user data symbol followed by a 1-to-N expander $1\uparrow N$ of each data symbol into an N chip sequence using the sign transfer of the Walsh chips.~~

~~For complex data symbols $\{Z(u)\}$ the sign-expander operation **18** generates the N-chip sequence $Z(u,n) = Z(u)\mathrm{sgn}\{W(u,n)\} = Z(u)W(u,n)$ for $n=0,1,\ldots,N-1$ for each user $u=0,1,\ldots,N-1$. This Walsh encoding serves to spread each user data symbol into an orthogonally encoded chip sequence which is spread over the CDMA communications frequency band. The Walsh encoded chip sequences for each of the user data symbols are summed over the users **19** followed by PN encoding with the scrambling sequences $[P_R(n)+jP_I(n)]$ **21**. PN encoding is implemented by transferring the sign of each PN chip to the summed chip of the Walsh encoded data symbols. Output is the stream of complex CDMA encoded chips $\{Z(n)\}$ **22**. The switch **20** selects the appropriate signal processing path for the complex and real data symbols~~.

~~For real data symbols $\{R(u_R)+jI(u_I)\}$ the real and imaginary communications axis data symbols are separately Walsh encoded **18**, summed **19**, and then PN encoded **19** to provide orthogonality between the channels along the real and imaginary communications axes. Output is complex combined **19** and PN encoded with the scrambling sequence $[P_R(n)+ jP_I(n)]$ **21**. Output is the stream of complex CDMA encoded chips $\{Z(n)\}$ **22**.~~

~~It should be obvious to anyone skilled in the communications art that this example implementation in FIG. 2 clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.~~

~~FIG. **3** CDMA receiver block diagram is representative of a current CDMA receiver which includes an implementation of the current real Walsh CDMA decoding in equations **(2)**. This block diagram becomes a representative implementation of the CDMA receiver which implements the new complex Walsh CDMA decoding when the current real Walsh CDMA decoding **27** is replaced by the new complex Walsh CDMA decoding of this invention. FIG. **3** signal processing starts with the user transmitted wavefronts incident at the receiver antenna **23** for the n_u users $u = 1, \ldots, n_u \leq N_c$. These wavefronts are combined by addition in the antenna to form the receive (Rx) signal $\hat{v}(t)$ at the antenna output **23** where $\hat{v}(t)$ is an estimate of the transmitted signal v(t) **16** in FIG. **1**, that is received with errors in time Δt, frequency Δf, phase Δθ, and with an estimate $\hat{z}(t)$ of the transmitted complex baseband signal z(t) **16** in FIG. **1**. This received signal $\hat{v}(t)$ is amplified and downconverted by the analog front end **24** and then synchronized and analog-to-digital (ADC) converted **25**. Outputs from the ADC are filtered and chip detected **26** by the fullband chip detector, to recover estimates $\{\hat{Z}(n) = \hat{R}(n) + j\hat{I}(n)\}$ **28** of the transmitted signal which is the stream of complex CDMA encoded chips {Z(n)=R(n)+jI(n)} **14** in FIG. **1** for both complex and real data symbols. The CDMA decoder **27** implements the algorithms in equations **(2)** by stripping off the PN code(s) and decoding the received CDMA real Walsh orthogonally encoded chips to recover estimates $\{\hat{Z}(u) = \hat{R}(u_R) + j\hat{I}(u_I)\}$ **29** of the transmitted user data symbols $\{Z(u) = R(u_R) + jI(u_I)\}$ **12** in FIG. **1**. Notation introduced in FIG. **1** and **3** assumes that the user index $u=u_R=u_I$ for complex data symbols, and for real data symbols the user index u is used for counting the user pairs (u_R, u_I) of real and complex data symbols. These estimates are processed by the symbol decoder **30** and the frame processor **31** to recover estimates **32** of the transmitted user data words.~~

~~**It should be obvious to anyone skilled in the communications art that this example implementation clearly defines the fundamental current CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.**~~

~~FIG. **4** real Walsh CDMA decoding is a representative implementation of the real Walsh CDMA decoding **27** in FIG. **3** and in equations **(2)**. Inputs are the received estimates of the complex CDMA encoded chips~~ $\cancel{\{\hat{Z}(n)\}}$ ~~**33**. The PN scrambling code is stripped off from these chips **34** by changing the sign of each chip according to the numerical sign of the real and imaginary components of the complex conjugate of the PN code as per the decoding algorithms **8** in equations **(2)**.~~

~~For complex data symbols **35** the real Walsh channelization coding is removed by a pulse compression operation consisting of multiplying each received chip by the numerical sign of the corresponding Walsh chip for the user and summing the products over the N Walsh chips **36** to recover estimates~~ $\cancel{\{\hat{Z}(u)\}}$ ~~of the user complex data symbols {Z(u)}. The switch **35** selects the appropriate signal processing path for the complex and real data symbols.~~

~~For real data symbols **35** the next signal processing operation is the removal of the PN codes from the real and imaginary axes. This is followed by stripping off the real Walsh channelization coding by multiplying each received chip by the numerical sign of the corresponding Walsh chip for the user and~~

~~summing the products over the N Walsh chips **36** to recover estimates $\{\hat{R}(u_R), \hat{I}(u_I)\}$ of the user real data symbols $\{R(u_R), I(u_I)\}$.~~

~~It should be obvious to anyone skilled in the communications art that this example implementation clearly defines the fundamental current CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.~~

~~**For cellular applications the transmitter description describes the transmission signal processing applicable to this invention for both the hub and user terminals, and the receiver describes the corresponding receiving signal processing for the hub and user terminals for applicability to this invention.**~~

SUMMARY OF THE INVENTION

~~**SUMMARY OF INVENTION**~~

This invention is a new approach to the application of Walsh orthogonal codes for CDMA, which offers to replaces the current real Walsh codes with ~~the new~~ complex Walsh codes called hybrid Walsh codes ~~and~~ with generalized complex Walsh codes called generalized hybrid Walsh codes~~the~~ which allow greater flexibility in the selection of the code lengths and enable other codes to be combined with the hybrid Walsh. ~~hybrid complex Walsh codes disclosed in this invention. Real Walsh~~

~~codes are used for current CDMA applications and will be used for all of the future CDMA systems. This invention of complex Walsh codes will provide the choice of using the new complex Walsh codes or the real Walsh codes since the real Walsh codes are the real components of the complex Walsh codes. This~~ A useful property is that ~~means~~ an application capable of using the complex Walsh codes can simply turn-off the complex axis components of the complex Walsh codes for real Walsh CDMA coding and decoding. Hybrid Walsh codes are the closest possible approximation to the DFT with orthogonal code vectors taking the values {1+j, -1+j, -1-j, 1-j} or equivalently the values {1, j, -1, -j} and are constructed with reordering permutations of the real Walsh. Generalized hybrid Walsh codes are constructed by combining other codes using tensor product construction, direct sum construction, and functional combining.

~~The complex Walsh codes of this invention are proven to be the natural development for the Walsh codes and therefore are the correct complex Walsh codes to within arbitrary factors that include scale and rotation, which are not relevant to performance. This natural development of the complex Walsh codes in the N-dimensional complex code space~~ ~~C^N~~ ~~extended the correspondences between the real Walsh codes and the Fourier codes in the N-dimensional real code space~~ ~~R^N,~~ ~~to correspondences between the complex Walsh codes and the discrete Fourier transform (DFT) codes in~~ ~~C^N.~~

~~The new 4-phase complex Walsh orthogonal CDMA codes provide fundamental performance improvements compared to the 2-phase real Walsh codes which include an increase in the carrier-to-noise ratio (CNR) for data symbol recovery in the receiver, lower correlation side-lobes under timing offsets both with and without PN spreading, lower levels of harmonic interference caused by non-linear amplification of multi-carrier CDMA signals, and reduced phase tracking jitter for code tracking to support both acquisition and synchronization. These potential performace~~

~~improvements simply reflect the widely known principle that complex CDMA is better than real CDMA.~~

~~The new hybrid complex Walsh orthogonal CDMA codes increase the choices for the code length by allowing the combined use of complex Walsh and discrete Fourier transform complex orthogonal codes using a Kronecker ceonstruction, direct sum constructioin, as well as the possibility for more general functional combining.~~

~~**BRIEF DESCRIPTION OF DRAWINGS AND PERFORMACE DATA**~~

BRIEF DESCRIPTION OF THE DRAWINGS AND THE PERFORMANCE DATA

The above-mentioned and other features, objects, design algorithms, implementations, and performance advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings and performance data wherein like reference characters and numerals denote like elements, and in which:

~~FIG. **1** is a representative CDMA transmitter signal processing implementation block diagram, with emphasis on the current real Walsh CDMA encoding which contains the signal processing elements addressed by this invention disclosure.~~

FIG. **1** depicts a represenative CDMA cellular network with the communications link between a base station and a user.

FIG. **2** depicts the CDMA transmit signal processing.

~~FIG. **2** is a representative CDMA encoding signal processing implementation diagram with emphasis on the current real Walsh CDMA encoding which contains the signal processing elements addressed by this invention disclosure.~~

~~FIG.3is a representative CDMA receiver signal processing implementation block diagram, with emphasis on the current real Walsh CDMA decoding which contains the signal processing elements addressed by this invention disclosure.~~

FIG. **3** depicts the receive CDMA signal processing.

~~FIG. **4** is a representative CDMA decoding signal processing implementation diagram, with emphasis on the current real Walsh CDMA decoding which contains the signal processing elements addressed by this invention disclosure.~~

FIG. **5** defines the implementation algorithm generating hybrid Walsh codes from real Walsh codes. ~~is a representative correlation plot of the correlation between the complex discrete Fourier transform (DFT) cosine and sine code component vectors and the real Fourier transform cosine and sine code component vectors.~~

FIG. **6** ~~is a representative~~depicts the hybrid Walsh transmit signal processing. ~~CDMA encoding signal processing implementation diagram with emphasis on the new complex Walsh CDMA encoding which contains the signal processing elements addressed by this invention disclosure~~

FIG. **7** depicts the hybrid Walsh receive signal processing. ~~is a representative CDMA decoding signal processing implementation diagram with emphasis on the new complex Walsh CDMA decoding which contains the signal processing elements addressed by this invention disclosure.~~

~~DISCLOSURE OF INVENTION~~

DISCLOSURE OF THE INVENTION

~~Real orthogonal CDMA code space R^N for Hadamard, Walsh, and Fourier codes:~~

The new complex Walsh orthogonal CDMA codes which are the hybrid Walsh codes in this invention disclosure are derived from the current real Walsh codes by starting with the correspondence of the current real Walsh codes with the discrete Fourier transform (DFT) basis vectors. ~~Consider the~~ The real orthogonal ~~CDMA code space R^N consisting of N-orthogonal real code vectors. Examples of code sets in R^N include the~~ Hadamard~~,~~ and Walsh, codes in the N-dimensional real code space R^N and ~~Fourier~~the complex orthogonal DFT codes in the N-dimensional complex code space C^N are defined in equations **(3)**.~~. The corresponding matrices of code vectors are designated as H, W, F respectively and as~~ defined in equation~~s~~ **(~~1~~3)** in which N=2^M with M an integer. ~~respectively consist of N-rows of N-chip code vectors.~~ Hadamard codes in their reordered form known as Walsh codes are used in the current CDMA, in the ~~proposals for the next generation~~ G3 CDMA, and in the proposals for all future CDMA. Walsh codes reorder the Hadamard codes according to increasing sequency~~. These codes assumed +/-1 values. Sequency~~ which is the average rate of change of the sign of the codes. In these equations the even and odd property of the code vectors is in reference to the midpoint of the vectors similar to the concept of even and odd frequencies.~~and the reordering places the Walsh codes in correspondence to the DFT wherein sequency is in correspondence with frequency in the DFT.~~

~~It is important to note that the correspondence "sequency-frequency" only applies to the complex DFT matrix E~~

~~consisting of the N row vectors {E(u)= [E(u,0),…,E(u,N-1)} wherein the elements of E are $E(u,n)=e^{j(2\pi un/N)}$, u,n = 0,1,…,N-1}. Historically it has not been applied to the Fourier basis F in R^N.~~

~~Equations **(1)** define the three sets H,W,F of real orthogonal codes in R^N with the understanding that the H and W are identical except for the ordering of the code vectors. Hadamard **37** and Walsh **38** orthogonal functions are basis vectors in R^N and are used as code vectors for orthogonal CDMA channelization coding. Hadamard **37** and Walsh **38** equations of definition are widely known with examples given in Reference [6]. Likewise, the Fourier **39** equations of definition are widely known within the engineering and scientific communities, wherein~~

~~N chip real orthogonal~~ <u>Orthogonal</u> CDMA codes **(3)**

37 Hadamard codes

H = Hadamard NxN orthogonal code matrix ~~consisting of~~<u>with</u>

N rows of N chip code vectors

= [H(u)] matrix of row vectors H(u)

= [H(u,n)] matrix of elements H(u,n)

H(u) = Hadamard code vector u

= [H(u,0), H(u,1), …, H(u,N-1)]

= 1xN row vector of chips H(u,0),….,H(u,N-1)

H(u,n) = Hadamard code u chip n

= +/+1 possible values

$$= (-1)\wedge \left[\sum_{i=0}^{i=M-1} u_i n_i \right]$$

where $u = \sum_{i=0}^{i=M-1} u_i 2^i$ binary representation of u

$n = \sum_{i=0}^{i=M-1} n_i 2^i$ binary representation of n

38 Walsh codes

W = Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [W(u)] matrix of row vectors W(u)

= [W(u,n)] matrix of elements W(u,n)

W(u) =Walsh code vector u

= [W(u,0), W(u,1), …, W(u,N-1)]

$W_e(u)$ = Even Walsh code vector

= W(2u) for u=0,1,…,N/2-1

$W_o(u)$ = Odd Walsh code vectors

= W(2u-1) for u=1,…,N/2

W(u,n) = Walsh code u chip n

= +/+1 possible values

$$= (-1)\wedge \left[u_{M-1} n_0 + \sum_{i=1}^{i=M-1} (u_{M-1-i} + u_{M-i}) n_i \right]$$

39 ~~Fourier~~ DFT codes

E = DFT NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [E(u)] matrix of row vectors E(u)

= [E(u,n)] matrix of elements E(u,n)

E(u) = DFT code vector u

= [E(u,0), E(u,1), …, E(u,N-1)]

= 1xN row vector of chips E(u,0),….,E(u,N-1)

= C(u) + j S(u) for u=0,1,…,N-1

C(u) = Even code vectors for u=0,1,…,N-1

= [1, cos(2π u 1/N),…,cos(2π u (N-1)/N)]

S(u) = Odd code vectors for u=0,1,…,N-1

= [0, sin(2π u 1/N),…,sin(2π u (N-1)/N)]

E(u,n) = DFT code u chip n

= exp^j2π un/N

= cos(2π un/N) + jsin(2π un/N)

= N possible values on the unit circle

~~F = Fourier NxN orthogonal code matrix consisting of~~

~~N rows of N chip code vectors~~

~~= [F(u)] matrix of row vectors F(u)~~

$$\cancel{= \begin{bmatrix} C \\ S \end{bmatrix}}$$

~~C = N/2+1 x N matrix of row vectors C(u)~~

~~C(u) = Even code vectors for u=0,1,…,N/2~~

~~= [1, cos(2π u1/N),…,cos(2π u(N-1/N)]~~

~~S = N/2-1 x N matrix of row vectors S(u)~~

~~S(Δu) = Odd code vectors for u=N/2+Δu, Δu=1,2,…,N/2-1~~

~~= [sin(2π Δu 1/N),…,sin(2π Δu(N-1)/N)]~~

~~where F(u) = C(u) for u=0,1,…,N/2~~

~~= S(Δu) for Δu = u-N/2, u=N/2+1,…,N-1~~

~~the cosine C(u) and sine S(u) code vectors are the code vectors of the Fourier code matrix F.~~

~~Complex orthogonal CDMA code space~~ $\cancel{C^N}$ ~~for DFT codes: The DFT orthogonal codes are a complex basis for the complex N-dimensional CDMA code space~~ $\cancel{C^N}$ ~~and consist of the DFT harmonic code vectors arranged in increasing order of frequency. Equations **(4)** are the definition of the DFT code vectors. The DFT definition **40** is widely known within the engineering and scientific communities. Even and odd components of the DFT code vectors **41** are the real cosine code vectors {C(u)} and the imaginary sine code vectors {S(u)} where even and odd are referenced to the midpoint of the code vectors. These cosine and~~

~~sine code vectors are the extended set 2N of the N Fourier cosine and sine code vectors.~~

~~N-chip DFT complex orthogonal CDMA codes **(4)**~~

~~**40** DFT code vectors~~

~~E = DFT NxN orthogonal code matrix consisting of~~

~~N rows of N chip code vectors~~

~~= [E(u)] matrix of row vectors E(u)~~

~~= [E(u,n)] matrix of elements E(u,n)~~

~~E(u) = DFT code vector u~~

~~= [E(u,0), E(u,1), …, E(u,N-1)]~~

~~= 1xN row vector of chips E(u,0),….,E(u,N-1)~~

~~E(u,n) = DFT code u chip n~~

~~= $e^{j2\pi\ un/N}$~~

~~= cos(2π un/N) + jsin(2π un/N)~~

~~= N possible values on the unit circle~~

~~41Even and odd code vectors are the extended set of~~

~~Fourier even and odd code vectors in **39** equations (3_)~~

~~C(u) = Even code vectors for u=0,1,…,N-1~~

~~= [1, cos(2π u 1/N),…,cos(2π u (N-1)/N)]~~

~~S(u) = Odd code vectors for u=0,1,…,N-1~~

~~= [0, sin(2π u 1/N),…,sin(2π u (N-1)/N)]~~

~~E(u) = C(u) + j S(u) for u=0,1,…,N-1~~

FIG. **5A** defines the reordering permutation algorithm which constructs the real code vector $W_R(u)$ and the imaginary code vector $W_I(u)$ of the hybrid Walsh code vector $W(u)= W_R(u)+j\ W_I(u)$ from the real Walsh code vectors W(u). Code index u in **167** is the sequency index since the codes are arranged in lexicographic order with code index u equal to the sequency value for the code. This ordering of the hybrid WaLsh is identical to the frequency

ordering of the DFT which establishes the correspondence "sequency~frequency" meaning that the code index u=0,1,2,… is the sequency index for hybrid Walsh codes and is the frequency index for the DFT codes. Lexiographic in the context of the hybrid Walsh refers to the reordering with increasing sequency. The reordering in FIG. **5A** is a permutation or equivalent a reordering transformation of the real Walsh mapping onto the real and imaginary componenents of the hybrid Walsh in **168** and **169** respectively.

FIG. **5B** maps the algorithm in FIG. **5A** into an algorithm that constructs the real code vector $W_R(u)$ and the imaginary code vector $W_I(u)$ of the hybrid Walsh code vector $W(u)= W_R(u)+j\ W_I(u)$ from the even and odd Walsh code vectors $W_e(u)$ and $W_o(u)$ defined in equations **(3)**. The lexicographic reordering algorithm for the real axis code vectors **171** and the imaginary axis code vectors **172** is defined for the code or sequency index u in **170.**

~~Complex orthogonal CDMA code space C^N for complex Walsh codes: Step **1** in the derivation of the complex Walsh codes in this invention establishes the correspondence of the even and odd Walsh codes with the even and odd Fourier codes. Even and odd for these codes are with respect to the midpoint of the row vectors similar to the definition for the DFT vector codes **41** in equations **(4)**. Equations **(5)** identify the even and odd Walsh codes in the W basis in R^N. These even and odd Walsh codes can be placed in~~

~~Even and odd Walsh codes in R^N~~ ~~**(5)**~~

~~$W_e(u)$ = Even Walsh code vector~~

~~= W(2u) for u=0,1,…,N/2-1~~

~~$W_o(u)$ = Odd Walsh code vectors~~

~~= W(2u-1) for u=1,…,N/2~~

~~direct correspondence with the Fourier code vectors 39 in equations (3) using the DFT equations (4).~~ Sequency~frequency and even and odd correspondences ~~This correspondence is~~ are defined in equations **(6)** where the correspondence operator "~" represents the even and odd correspondence between the Walsh and ~~Fourier~~ DFT codes, and additionally represents the sequency~frequency correspondence~~nce.~~.

Hybrid Walsh ~ DFT correspondence **(6)**

for $u = 0$

$$E(0) = C(0) \sim W(0) = W_e(0)$$

for $u = 1,2,\ldots,N/2-1$

$$E(u) = C(u)+jS(u) \sim W(u) = W(2u) + jW(2u-1)$$
$$= W_e(u) + jW_o(u)$$

for $u = N/2$

$$E(N/2) = C(N/2) \sim W(N/2) = W_o(N/2)+jW_o(N/2)$$
$$= W(N-1)+jW(N-1)$$

for $u = N/2+\Delta u$ with $\Delta u = 1,2,\ldots,N/2-1$

$$E(u)=C(N/2-\Delta u)-jS(N/2-\Delta u)$$
$$\sim W(u) = W(N-1-\Delta_e i)+jW(N-1-\Delta_o u)$$
$$= W_o(N/2-\Delta u)+jW_e(N/2-\Delta u)$$ ~~Correspondence between Walsh and Fourier codes (6)~~

~~$W(0) \sim C(0)$~~

~~$W_e(u) \sim C(u)$ for $u=1,\ldots,N/2-1$~~

~~$W_o(u) \sim S(u)$ for $u=1,\ldots,N/2-1$~~

~~$W(N-1) \sim C(N/2)$~~

In these equations the indexing for the even real Walsh vectors is $\Delta_e u=2\Delta u$ and the indexing for the odd real Walsh vectors is

$\Delta_o u = 2\Delta u - 1$. This equation defines the lexicographic reordering algorithms and demonstrates their uniqueness.

The hybrid Walsh code matrix W derived from the algorithms in FIG. **5A,5B** is given in equations **(7)** for N=8 and has code values {1+j, -1+j, -1-j, 1-j}. With a -45° rotation and a rescaling by $1/\sqrt{2}$ which is implemented by the multiplicative constant $(1/\sqrt{2})\exp(-j\pi/4) = (1-j)/2$ the $W*(1-j)/2$ hybrid Walsh matrix has code values {1, j, -1, -j} on the unit circle in the complex plane with code values along the real and imaginary axes as shown in equations **(7)** and wherein "*" indicates multiplication.

$$W = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \end{bmatrix} + j \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \end{bmatrix} \quad (7)$$

$$W^*(1-j)/2 = [\, W(u,n)^*(1-j)/2 \,] = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 & -1 & -j & -j \\ 1 & j & -1 & -j & 1 & j & -1 & -j \\ 1 & -1 & -j & j & -1 & 1 & j & -j \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & j & -j & -1 & 1 & -j & j \\ 1 & -j & -1 & j & 1 & -j & -1 & j \\ 1 & 1 & -j & -j & -1 & -1 & j & j \end{bmatrix}$$

~~Step **2** derives the set of N complex DFT vector codes in C^N from the set of N real Fourier vector codes in R^N. This means that the set of 2N cosine and sine code vectors in **41** in equations **(4)** for the DFT codes in C^N will be derived from the set of N cosine and sine code vectors in **39** in equations **(3)** for the Fourier codes in R^N. The first N/2+1 code vectors of the DFT basis can be written in terms of the Fourier code vectors in equations **(7)**.~~

~~DFT code vectors 0,1,…,N/2 derived from Fourier~~

~~(7)~~

~~42Fourier code vectors from **39** in equations **(3)** are~~

~~$C(u)$ = Even code vectors for $u=0,1,\ldots,N/2$~~

~~$= [1, \cos(2\pi\, u1/N), \ldots, \cos(2\pi\, u(N-1/N)]$~~

~~$S(u)$ = Odd code vectors for $u=1,2,\ldots,N/2-1$~~

~~$= [\sin(2\pi\, u1/N), \ldots, \sin(2\pi\, u(N-1)/N)]$~~

~~43DFT code vectors in **41** of equations (4) are written as functions of the Fourier code vectors~~

~~E(u) = DFT complex code vectors for u=0,1,…,N/2~~

~~= C(0)~~

~~= C(u)+jS(u) for u=1,…,N/2-1~~

~~= C(N/2) for u=N/2~~

~~The remaining set of N/2+1,…,N-1 DFT code vectors in~~ $\cancel{C^N}$ ~~can be derived from the original set of Fourier code vectors by a correlation which establishes the mapping of the DFT codes onto the Fourier codes. We derive this mapping by correlating the real and imaginary components of the DFT code vectors with the corresponding even and odd components of the Fourier code vectors. The correlation operation is defined in equations **(8)**~~

~~Correlation of DFT and Fourier code vectors **(8)**~~

~~Corr(even) = C*Real{E'}~~

~~= Correlation matrix~~

~~= Matrix product of C* and the real part of E transpose~~

~~Corr(odd) = S*Imag{E'}~~

~~= Correlation matrix~~

~~= Matrix product of S and the imaginary part of E transpose~~

~~**and the results of the correlation calculations are plotted in FIG.** 5 **for N=32 for the real cosine and the odd sine Fourier code vectors. Plotted are the correlation of the 2N DFT cosine and sine codes against the N Fourier cosine and sine codes which range from -15 to +16 where the negative indices of the codes represent a negative correlation value. The plotted curves are the correlation peaks. These correlation curves in FIG. 5 prove that the**~~

~~**remaining N/2+1,…,N-1 code vectors of the DFT are derived from the Fourier code vectors by equations** (9)~~

~~**DFT code vectors N/2+1,…, N-1 derived from Fourier** (9)~~

~~E(u) = C(N/2 -Δu) - jS(N/2-Δu)~~

~~for u = N/2 + Δu~~

~~**Δu = 1,…,N/2-1**~~

~~This construction of the remaining DFT basis in equations **(9)** is an application of the DFT spectral foldover property which observes the DFT harmonic vectors for frequencies fNT=N/2+Δi above the Nyquist sampling rate fNT=N/2 simply foldover such that the DFT harmonic vector for fNT = N/2+Δi is the DFT basis vector for fNT = N/2-Δi to within a fixed sign and fixed phase angle of rotation.~~

~~Step 3 derives the complex Walsh code vectors from the real Walsh code vectors by using the DFT derivation in equations **(7)** and **(9)**, by using the correspondences between the real Walsh and Fourier in equations **(6)**, and by using the fundamental correspondence between the complex Walsh and the complex DFT given in equation **(10)**. We start by constructing the complex~~

~~Correspondence between complex Walsh and DFT **(10)**~~

~~$\tilde{W}$ ~ E NxN complex DFT orthogonal code matrix~~

~~where = NxN complex Walsh orthogonal code matrix~~

~~= N rows of N chip code vectors~~

~~= [$\tilde{W}$(u)] matrix of row vectors $\tilde{W}$(u)~~

~~= [$\tilde{W}$(u,n)] matrix of elements $\tilde{W}$(u,n)~~

~~$\tilde{W}$(u) = Complex Walsh code vector u~~

~~= [$\tilde{W}$(u,0), $\tilde{W}$(u,1), …, $\tilde{W}$(u,N-1)]~~

~~$\tilde{W}$ = +/-1 +/- j possible value~~

~~Walshde code vector $\tilde{W}$(0). We use equation E(0)=C(0) in~~ **43** ~~in equations **(7)**, the correspondence in equations **(6)**, and observe that the dc complex Walsh vector has both real and~~

~~imaginary components in the $\widetilde{W}$ domain, to derive the dc complex Walsh code vector:~~

~~$\widetilde{W}(0) = W(0) + jW(0)$ for u=0 **(11)**~~

~~For complex Walsh code vectors $\widetilde{W}(u)$, u=1,2,…,N/2-1, we apply the correspondences in equations **(10)** between the complex Walsh and DFT bases, to the DFT equations **43** in equations **(7)**:~~

~~$\widetilde{W}(u) = W_e(u) + jW_o(u)$ for u=1,2,…,N/2-1 **(12)**~~

~~$= W(2u) + jW(2u-1)$ for u=1,2,…,N/2-1~~

~~For complex Walsh code vector $\widetilde{W}(N/2)$ we use the equation E(N/2)=C(N/2) **43** in equations **(7)** and the same rationale used to derive equation (11), to yield the equation for .~~

~~$\widetilde{W}(N/2) = W(N-1) + jW(N-1)$ for u=N/2 **(13)**~~

~~For complex Walsh code vectors $\widetilde{W}(N/2+\Delta u)$, Δu=1,2,…,N/2-1 we apply the correspondences between the complex Walsh and DFT bases to the spectral foldover equation E(N/2+Δu)=C(N/2-Δu)-jS(N/2-Δu) in equations **(9)** with the changes in indexing required to account for the W indexing in equations **(5)**. The equations are~~

~~$\widetilde{W}(N/2+\Delta u) = W(N-1-\Delta eu)+W(N-1-\Delta ou)$ for u=N/2+1,…,N-1 **(14)**~~

~~$= W(N-1-2\Delta u) + jW(N-2\Delta u)$ for u=N/2+1,…,N-1~~

~~using the notation Δei=2Δi, Δoi=2Δi-1. These complex Walsh code vectors in equations **(11)**, **(12)**, **(13)**, **(14)** are the equations of definition for the complex Walsh code vectors.~~

~~An equivalent way to derive the complex Walsh code vectors in C^N from the real Walsh basis in R^{2N} is to use a sampling technique which is a known method for deriving a complex basis in C^N from a real basis in R^N~~

~~Transmitter equations **(15)** describe a representative complex Walsh CDMA encoding for the transmitter in FIG. **1**. It is~~

~~assumed that there are N complex Walsh code vectors $\tilde{W}(u)$~~ ~~**44**~~ ~~each of length N chips similar to the definitions for the real Walsh code vectors~~ ~~**1**~~ ~~in equations~~ ~~**(1)**.~~ ~~The code vector is presented by a 1xN N-chip row vector $\tilde{W}(u)=[\tilde{W}(u,0),...,\tilde{W}(u,N-1)]$ where $\tilde{W}(u,n)$ is chip n of code u. The code vectors are the row vectors of the complex Walsh matrix $\tilde{W}$. Walsh code chip n of code vector u has the possible values $\tilde{W}(u,n)=+/-1+/-j$. Each user is assigned a unique Walsh code which allows the code vectors to be designated by the user symbols $u=0,1,\ldots,N-1$ for N complex Walsh codes. The complex Walsh code vectors $\tilde{W}(u)$ derived in equations~~ ~~**(11),(12),(13),(14)**~~ ~~are summarized~~ ~~**44**~~ ~~in terms of their real and imaginary component code vectors $\tilde{W}(u)=W_R(u)+jW_I(u)$ where $W_R(u)$ and $W_I(u)$ are respectively the real and imaginary component code vectors. As per the derivation of $\tilde{W}(u)$ the sets of real axis code vectors $\{W_R(u)\}$ and the imaginary axis code vectors $\{W_I(u)\}$ both consist of the real Walsh code vectors in R^N with the ordering modified to ensure that the definition of the complex Walsh vectors satisfies equations~~ ~~**(11), (12), (13), (14)**.~~

~~Complex Walsh CDMA encoding for transmitter~~ ~~**(15)**~~

~~**44** Complex Walsh codes use the definitions~~

~~for the real Walsh codes in~~ ~~**1**~~ ~~equations~~ ~~**(1)**~~ ~~and~~

~~the definitions of the complex Walsh codes in~~

~~equations~~ ~~**(11), (12), (13), (14)**~~ ~~We find~~

~~$\tilde{W}$ = complex Walsh NxN orthogonal code matrix~~

~~consisting of N rows of N chip code vectors~~

~~$= [\tilde{W}(u)]$ matrix of row vectors $\tilde{W}(u)$~~

~~$= [\tilde{W}(u,n)]$ matrix of elements $\tilde{W}(u,n)$~~

~~$\tilde{W}(u)$ = complex Walsh code vector u~~

~~$= W_R(u) + jW_I(u)$ for $u=0,1,\ldots,N-1$~~

~~where~~

~~$W_R(u)$ = Real{ $\tilde{W}(u)$ }~~

~~= W(0) for u=0~~

~~= W(2u) for u=1,2,…,N/2-1~~

~~= W(N-1) for u=N/2~~

~~= W(2N-2u-1) for u=N/2+1,…,N-1~~

~~$W_I(u)$ = Imag{ $\tilde{W}(u)$ }~~

~~= W(0) for u=0~~

~~= W(2u-1) for u=1,2,…,N/2-1~~

~~= W(N-1) for u=N/2~~

~~= W(2N-2u) for u=N/2+1,…,N-1~~

~~$\tilde{W}(u,n)$ = complex Walsh code u chip n~~

~~= +/-1 +/-j possible values~~

~~**45** Data symbols~~

~~Z(u) = Complex data symbol for user u~~

~~= R(u) + jI(u)~~

~~**46** Complex Walsh encoded data~~

~~Z(u,n) = Z(u) $\tilde{W}(u,n)$~~

~~= Z(u)[sgn{$W_R(u,n)$} + jsgn{$W_I(u,n)$}]~~

~~= [R(u)sgn{$W_R(u,n)$} - I(u)sgn{$W_I(u,n)$}]~~

~~+ j[R(u)sgn{$W_I(u,n)$ + I(u,n)sgn{$W_R(u,n)$}]~~

~~47 PN scrambling~~

~~$P_R(n)$ = Chip n of the PN code for the real axis~~

~~$P_I(n)$ = Chip n of the PN code for the imaginary axis~~

~~Z(n) = PN scrambled complex Walsh encoded data chips after summing over the users~~

~~= $\sum_u Z(u,n)\,P_2(n)\,[P_R(n) + j\,P_I(n)]$~~

~~= $\sum_u Z(u,n)\,sign\{P_2(n)\}\,[sign\{P_R(n)\} + j\,sign\{P_I(n)\}]$~~

~~= Complex Walsh CDMA encoded chips~~

~~User data symbols **45** are the set of complex symbols $\{Z(u),\ u=0,1\ldots,N-1\}$. These data symbols are encoded by the Walsh CDMA codes **46**. Each of the user symbols $Z(u)$ is assigned a unique complex Walsh code $\tilde{W}(u)=W_R(u)+jW_I(u)$. Complex Walsh encoding of each user data symbol generates an N-chip sequence with each chip in the sequence consisting of the user data symbol with the complex sign of the corresponding complex Walsh code chip, which means each encoded chip = [Data symbol $Z(u)$] x [Sign of $W_R(u)$ + j sign of $W_I(u)$].~~

~~The complex Walsh encoded data symbols are summed and encoded with PN scrambling codes **47**. These PN codes are defined **4** in equations **(1)** as a complex PN for each chip n, equal to $[P_R(u) + j\ P_I(u)]$ where $P_R(u)$ and $P_I(u)$ are the respective PN scrambling codes for the real and imaginary axes. Encoding with the complex PN is the same as given **4** in equations **(1)** for complex data symbols. Each complex Walsh encoded data chip $Z(u,n)$ **46** is summed over the set of users $u=0,1,\ldots,N-1$ and complex PN encoded to yield the complex Walsh CDMA chips $Z(n) = \sum_u Z(u,n)\ P_2(n)\ [P_R(n) + j\ P_I(n)]$ **47**.~~

~~Although not considered in this example, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA encoding in equations **(1)** since the complex Walsh code vectors are the real Walsh code vectors along the real axis and a reordering of the real Walsh code vectors along the imaginary axis.~~

~~Receiver equations **(16)** describe a representative complex Walsh CDMA decoding for the receiver in FIG. **3**. The receiver front end **48** provides estimates $\{\hat{Z}(n)\}$ of the transmitted complex Walsh CDMA encoded chips $\{Z(n)\}$ for the complex data symbols $\{Z(u)\}$. Orthogonality property **49** is expressed as a matrix product of the complex Walsh code chips or equivalently as~~

~~a matrix produce of the complex Walsh code chip numerical signs of the real and imaginary components. The 2-phase PN codes **50** have the useful decoding property that the square of each code chip is unity which is equivalent to observing that the square of each code chip numerical sign is unity. Decoding algorithms **51** perform the inverse of the signal processing for the encoding in equations **(15)** to recover estimates~~ $\cancel{\{\hat{Z}(u)\}}$ ~~of the transmitter user symbols {Z(n)} for the complex data symbols {Z(u)}.~~

~~Complex Walsh CDMA decoding for receiver **(16)**~~

~~48Receiver front end in FIG. **3** provides estimates~~

~~$\{\hat{Z}(n)\}$ **28** of the encoded transmitter chip symbols {Z(n)} **47** in equations **(15)**.~~

~~**49**Orthogoality property of complex Walsh NxN matrix $\widetilde{W}$~~

$$\cancel{\sum_{n} \widetilde{W}(\hat{u},n)\,\widetilde{W}'(n,u)} =$$

$$\cancel{\sum_{n} [\text{sgn}\{W_R(\hat{u},n)\} + j\text{sgn}\{W_I(\hat{u},n)\}][\text{sgn}\{W_R(n,u) - j\text{sgn}\{W_I(n,u)\}]}$$

$$\cancel{= 2N\,\delta(\hat{u}, u)}$$

~~where $\delta(\hat{u}, u)$ = Delta function of $\hat{u}$ and u~~

~~= 1 for $\hat{u}$ = u~~

~~= 0 otherwise~~

~~**50**PN decoding property~~

~~P(n)P(n) = sgn{P(n)} sgn{P(n)}~~

~~= 1~~

~~**51** Decoding algorithm~~

$$\hat{Z}(u) =$$

$$\cancel{2^{-1}N^{-1}\sum_{n}\hat{Z}(n)\,sign\{P_2(n)\}\,[sign\{P_R(n)\} - j\,sign\{P_I(n)\}]^*}$$

$$[sign\{W_R(n,u)\} - j\,sign\{W_I(n,u)\}]$$

~~= Receiver estimate of the transmitted data symbol Z(u) **45** in equations **(15)**~~

~~Although not considered in this example, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA decoding in FIG. 4 since the complex Walsh code vectors are the real Walsh code vectors along the real axis and a reordering of the real Walsh code vectors along the imaginary axisFIG. 6 complex Walsh CDMA encoding is a representative implementation of the complex Walsh CDMA encoding which will replace the current real Walsh encoding **13** in FIG. **1** and is defined in equations **(15)**. Inputs are the user data symbols {Z(u)} **52**. Encoding of each user by the corresponding complex Walsh code is described in **53** by the implementation of transferring the sign +/-1+/-j of each complex Walsh code chip to the user data symbol followed by a 1-to-N expander 1↑N of each data symbol into an N chip sequence using the sign transfer of the complex Walsh chips. The sign-expander operation **53** generates the N-chip equence~~ ~~$Z(u,n)=Z(u)\{sgn\{W_R(u,n)\}+jsgn\{W_I(u,n)\}\}= Z(u)\{W_R(u,n)+jW_I(u,n)\}$ for n=0,1,…,N-1 for each user u=0,1,…,N-1. This complex Walsh encoding serves to spread each user data symbol into an orthogonally encoded chip sequence which is spread over the CDMA communications frequency band. The complex Walsh encoded chip sequences for each of the user data symbols are summed over the users **54** followed by PN encoding with the scrambling sequence $[P_R(n)-jP_I(n)]$ **55**. PN encoding is implemented by transferring the sign of each PN chip to the summed chip of the Walsh encoded data symbols. Output is the stream of complex CDMA encoded chips {Z(n)} **56**.~~

FIG. **6** describes the CDMA transmit signal processing for the cellular network in FIG. **1** using the hybrid Walsh complex channelization codes in place of the real Walsh codes. FIG. **6** depicts a representative embodiment of the transmitter signal

processing for the forward and reverse CDMA links **106** in FIG. **1** between the base station and the user for CDMA2000 and W-CDMA. Similar to FIG. **2** the data inputs are the inphase data symbols R **173** and quadrature data symbols I **174**. Inphase **175** hybrid Walsh codes W_R are generated in **168** in Fig. **5A** and in **171** in FIG. **5B**. Quadrature **176** hybrid Walsh codes W_I are implemented in **169** in FIG. **5A** and in **172** in FIG. **5B**. A complex multiply **177** encodes the data symbols with the hybrid Walsh W codes in the encoder using the inphase (real) W_R and quadrature (imaginary) W_I code components of $W=W_R+jW_I$ to generate a rate R=N set of hybrid Walsh encoded data chips for each inphase and quadrature data symbol. Following the hybrid Walsh encoding the transmit signal processing in **178-to-189** is identical to the corresponding transmit signal processing in **122-to-133** in FIG. **2**.

FIG. **6** depicts an embodiment of the upgrade to the current CDMA transmitter art using the hybrid Walsh codes in place of the real Walsh codes and with current art signal processing changes this figure is representative of the use of hybrid Walsh codes in place of the real Walsh codes for other current art CDMA receiver embodiments of this invention disclosure. Other embodiments of the CDMA transmitter include changes in the ordering of the signal processing, single channel versus multi-channel hybrid Walsh encoding, summation or combining of the hybrid Walsh channels by summation over like chip symbols, analog versus digital signal representation, baseband versus intermediate frequency IF CDMA processing, the order and placement in the signal processing thread of the Σ, LPF, and D/A signal processing operations, and the up-conversion processing. The order of the rate R=1 PN code multiplies in FIG. **6** can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short code complex multiply **180,181,182** in FIG. **6** can occur prior to the long code multiply **178,179** and

moreover the long code can be complex with the real multiply **179** replaced by the equivalent complex multiply **182.**

~~Although not considered in this example, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA encoding in FIG. **2** since the complex Walsh code vectors are the real Walsh code vectors along the real axis and a reordering of the real Walsh code vectors along the imaginary axis.~~

~~It should be obvious to anyone skilled in the communications art that this example implementation in FIG. **6** clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.~~

~~FIG. **7** complex Walsh CDMA decoding is a representative implementation of complex Walsh CDMA decoding which will replace the current real Walsh decoding **27** in FIG. **3**, and defined in equations **(15)**. Inputs are the received estimates of the complex CDMA encoded chips~~ $\cancel{\{\hat{Z}(n)\}}$ ~~**57**. The PN scrambling code is stripped off from these chips **58** by changing the sign of each chip according to the numerical sign of the real and imaginary components of the complex conjugate of the PN code as per the decoding algorithms **50** in equations **(16)**.~~

~~The complex Walsh channelization coding is removed by a pulse compression operation consisting of multiplying each received chip by the numerical sign of the corresponding complex Walsh chip for the user and summing the products over the N Walsh chips **59** to recover estimates~~ $\cancel{\{\hat{Z}(u)\}}$ ~~of the user complex data symbols {Z(u)}.~~

FIG. **7** is the upgrade to the cellular network receive CDMA decoding in FIG. **1** using the hybrid Walsh complex channelization codes in place of the real Walsh codes. FIG. **7** depicts a representative embodiment of the receiver signal processing for the forward and reverse CDMA links **106** in FIG. **1** between the base station and the user for CDMA2000 and W-CDMA that implements the CDMA decoding for the decovering by the long code and the short complex codes followed by the hybrid Walsh decoding to recover estimates of the transmitted inphase (real) data symbols R **173** and quadrature (imaginary) data symbols I **174** in FIG. **6.** Depicted are the principal signal processing that is relevant to this invention disclosure. Similar to FIG. **3** the signal input $\hat{v}(t)$ **190** is the received estimate of the transmitted CDMA signal v(t) **189** in FIG. **6.** The receive signal recovery in **191-to-201** is identical to the corresponding receive signal processing in **135-to-145** in FIG. **3.** The decovered chip symbols are rate R=1/N decoded by the hybrid Walsh complex decoder **204** using the complex conjugate of the hybrid Walsh code structured as the inphase hybrid Walsh code W_R **202** and the negative of the quadrature hybrid Walsh code $(-)W_I$ **203** to implement the complex conjugate of the hybrid Walsh code in the complex multiply and decoding operations. Decoded output symbols are the inphase data symbol estimates $\hat{R}$ **205** and the quadrature data symbols $\hat{I}$ **206.**

FIG. **7** depicts an embodiment of the upgrade to the current CDMA receiver art using the hybrid Walsh code in place of the real Walsh code and with current art signal processing changes this figure is representative of the use of hybrid Walsh codes in place of the real Walsh codes for other current art CDMA receiver embodiments of this invention disclosure. Other embodiments of the CDMA receiver include changes in the ordering of the signal processing, analog versus digital signal representation, down-conversion processing, baseband versus IF frequenncy CDMA processing, the order and placement in the signal processing

thread of the Σ, LPF, and A/D signal processing operations, and single channel versus multi-channel hybrid Walsh decoding, The order of the rate R=1 PN code multiplies in FIG. **7** which perform the code decovering can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short code complex multiply **197,198,199** can occur after to the long code multiply **200,201** and moreover the long code can be complex with the real multiply **201** replaced by the equivalent complex multiply **199.**

Although not considered in ~~this~~ these examples ~~example~~, it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA ~~decoding in FIG. 4~~ since the complex Walsh code vectors are the reordered real Walsh code vectors along the real axis and a distinct reordering of the real Walsh code vectors along the imaginary axis.

It should be obvious to anyone skilled in the communications art that ~~this~~ these example implementations in FIG. 6, 7 clearly define~~s~~ the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

For cellular applications the transmitter description describes the transmission signal processing applicable to this invention for both the hub and user terminals, and the receiver describes the corresponding receiving signal processing for the hub and user terminals for applicability to this invention.

~~Complex orthogonal CDMA code space C^N for hybrid complex Walsh codes: The~~Generalized hybrid Walsh codes ~~power of 2 code lengths N=2^M where M is an integer, for complex Walsh can be modified to~~ allow the code length N to be a product of powers of primes **60** in equations **(17)** or a sum of powers of primes **61** in equations **(17)**, at the implementation cost of introducing multiply operations into the CDMA encoding and decoding. In the previous disclosure of this invention ~~we used~~the N was assumed to be equal to a power of 2 which means N=2^~~m~~ M corresponding to prime $p_0 = 2$ and the integer $M=m_0$. This restriction was made for convenience in explaining the construction of the ~~complex~~ hybrid Walsh and is not required since it is well known that Hadamard matrices exist for non-integer powers of 2 and, therefore, ~~complex~~ hybrid Walsh matrices exist for non-integer powers of 2.

Length N of generalized hybrid Walsh ~~hybrid complex~~ codes **(17)**

60 ~~Kronecker~~ Tensor product code construction

$$N = \prod_k p_k\hat{\ }m_k$$

$$= \prod_k N_k$$

where

~~p_k~~ p_k = prime number indexed by k starting with k=0

m_k = order of the prime number p_k

N_k = Length of code for the prime p_k

= ~~$p_k^{m_k}$~~ p_k^m_k

61 Direct sum code construction

$$N = \sum_k p_k\text{^}m_k$$

$$= \sum_k N_k$$

Add-only arith~~e~~metic operations are required for encoding and decoding both real Walsh and ~~complex~~ hybrid Walsh CDMA codes since the real Walsh values are +/-1 and the ~~complex~~ hybrid Walsh values are {+/-1 +/-j} or equivalently are {1,j,-1,-j} under a -90 degree rotation and normalization which means the only operations are sign transfer and adds plus subtracts ~~or~~ which are add-only algebraic operations. Multiply operations are more complex to implement than add operations. However, the advantages of having greater flexibility in choosing the orthogonal CDMA code lengths N using equations **(17)** can offset the expense of multiply operations for particular applications. Additioonally, the generalized hybrid Walsh codes be constructed to have designer coordinates and properties. Accordingly, this invention includes the concept of generalized hybrid ~~hybrid complex~~ Walsh orthogonal CDMA codes with the flexibility to meet these needs. This extended class of ~~complex~~ hybrid Walsh codes ~~are hybrid in that their construction~~ supplements the ~~complex~~ hybrid Walsh codes ~~with the use of~~by combining with Hadamard (or real Walsh), DFT, and other orthogonal codes as well as with quasi-orthogonal PN by relaxing the orthogonality property to quasi-orthogonality.

Generalized ~~H~~hybrid ~~complex~~ Walsh orthogonal CDMA codes can be constructed as demonstrated in **64** and **65** in equations **(18)** for the ~~Kronecker~~ tensor product, ~~and~~ in **66** ~~in equations (18)~~ for the direct sum, and in **67** for functional combining. ~~Code~~ The example code matrices considered for orthogonal CDMA codes in **62** ~~in equations (18)~~ for the construction of the generalized hybrid ~~complex~~ Walsh are the DFT E and Hadamard H or equivalently Walsh W, in addition to the ~~complex~~ hybrid Walsh ~~$\tilde{W}$~~ W. The algorithms and examples for the construction start with the definitions **63** of the NxN orthogonal code matrices ~~$\tilde{W}_N$,~~ $W=W_N$, $E=E_N$, $H=H_N$ ~~for $\tilde{W}$, E, H respectively, examples~~ for ~~low orders~~ N=2,4~~, .~~. and the equivalence of E_4 and ~~$\tilde{W}_4$~~ W_4 after the ~~$\tilde{W}_4$~~ W_4 is rotated through the angle -~~90~~ 45 degrees and rescaled. The CDMA current and developing standards use the prime 2 which generates a code length $N=2^M$ where M=integer. For applications requiring greater flexibility in code length N, additional primes can be used using the ~~Kronecker~~ tensor construction. ~~We~~ This flexibility is illustrated ~~this~~ in **65** with the addition of prime=3. The use of prime=3 in addition to the prime=2 in the range of N=8 to N=64 is observed to increase the number of N choices ~~from 4 to 9~~ at a modest cost penality of using multiples of the angle increment 30 degrees for prime=3 in addition to the angle increment 90 degrees for prime=2. As noted in **65** there are several choices in the ordering of the ~~Kronecker~~ tensor product construction and 2 of these choices are used in the construction. In general, different orderings of the tensor product yield different sets of orthogonal codes.

Direct sum construction provides greater flexibility in the choice of N without necessarily introducing a multiply penality. However, the addition of the zero matrix in the construction is generally not desirable for CDMA communications. A functional combining in **67** in equation **(18)** removes these zero matrices at

the cost of relaxing the orthogonality property to quasi-orthogonality.

~~Construction of~~ Generalized hybrid ~~hybrid complex~~ Walsh orthogonal codes **(18)**

62 Code matrices for orthogonal codes

$\cancel{\widetilde{W}_N}$ W = NxN ~~complex~~ hybrid Walsh ~~orthogonal code matrix~~W

E_N = NxN DFT ~~orthogonal code matrix~~E

H_N = NxN Hadamard ~~orthogonal code matrix~~H

63 Low-order code definitions and equivalences

$$2\text{x}2 \quad H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$= E_2$$

$$= (e^{-j\pi/4}/\sqrt{2}) * \cancel{\widetilde{W}_2} W_2$$

$$3\text{x}3 \quad E_3 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{j2\pi/3} & e^{j2\pi 2/3} \\ 1 & e^{j2\pi 2/3} & e^{j2\pi/3} \end{bmatrix}$$

$$4\text{x}4 \quad H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

$$\cancel{\widetilde{W}_4}\ \underline{W}_4 = \begin{bmatrix} 1+j & 1+j & 1+j & 1+j \\ 1+j & -1+j & -1-j & 1-j \\ 1+j & -1-j & 1+j & -1-j \\ 1+j & 1-j & -1-j & -1+j \end{bmatrix}$$

$$E_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

$$= (e^{-j\pi/4}/\sqrt{2})\underline{W}_4\ \cancel{\widetilde{W}_4}$$

64 ~~Kronecker~~ Tensor product construction for $N=\prod_k N_k$

~~Code matrix C_N = NxN hybrid orthogonal~~generalized

~~CDMA code matrix~~

~~Kronecker product construction of C_N~~

C_N = NxN generalized hybrid Walsh code natrux

$\cancel{C_N} =\ C_0 \prod_{k>0} \otimes C_{N_k}$

Where the tensor product "⊗" is defined as:

$A \otimes B$ = tensor product of matrix A and matrix B

= NxN matrix of elements [a_{ik} B]

~~Kronecker product definition~~

where A = $N_a x N_a$ orthogonal code matrix [a_{ik}}]

B = $N_b x N_b$orthogonal code matrix

N = $N_a N_b$

~~$A \otimes B$ = Kronecker product of matrix A and matrix B~~

~~= $N_a N_b$ x $N_a N_b$ orthogonal code matrix consisting~~

~~of the elements $[a_{ik}]$ of matrix A multiplied by the matrix B~~

~~$= [\, a_{ik} B \,]$~~

65 Generalized hybrid Walsh code matrix ~~Kronecker~~ Tensor product construction examples for primes p=2,3 and the range of sizes $8 \le N \le 64$

8x8	C_8	$= \cancel{\widetilde{W}_8}\, \underline{W}_8$
12x12	C_{12}	$= \underline{W}_4 \otimes \mathbf{E}_3$
	C_{12}	$= \mathbf{E}_3 \otimes \underline{W}_4$
16x16	C_{16}	$= \underline{W}_{16}$
18x18	C_{18}	$= \underline{W}_2 \otimes \mathbf{E}_3 \otimes \mathbf{E}_3$
	C_{18}	$= \mathbf{E}_3 \otimes \mathbf{E}_3 \otimes \underline{W}_2$
24x24	C_{24}	$= \underline{W}_8 \otimes \mathbf{E}_3$
	C_{24}	$= \mathbf{E}_3 \otimes \underline{W}_8$
32x32	C_{32}	$= \cancel{\widetilde{\mathbf{W}}_{32}}\, \underline{W}_{32}$
36x36	C_{36}	$= \underline{W}_4 \otimes \mathbf{E}_3 \otimes \mathbf{E}_3$
	C_{36}	$= \mathbf{E}_3 \otimes \mathbf{E}_3 \otimes \underline{W}_4$
48x48	C_{48}	$= \underline{W}_{16} \otimes \mathbf{E}_3$
	C_{48}	$= \mathbf{E}_3 \otimes \underline{W}_{16}$
64x64	C_{64}	$= \cancel{\widetilde{W}_{64}}\, \underline{W}_{64}$

66 Generalized Hyhbrid Walsh code matrices using~~**66** Direct~~ direct sum construction for $N=\sum_k N_k$

~~Code matrix C_N = NxN hybrid orthogonal CDMA code matrix~~

~~Direct sum construction of C_N~~

C_N = NxN generalized hybrid Walsh

$$C_N = C_0 \prod_{k>0} \oplus C_{N_k}$$

Where the ~~Direct~~ direct sum definition is:

A = $N_a x N_a$ orthogonal code matrix

B = $N_b x N_b$ orthogonal code matrix

$A \oplus B$ = Direct sum of matrix A and matrix B

= N_a+N_b x N_a+N_b orthogonal code matrix

$$= \left[\begin{array}{c|c} A & O_{N_a x N_b} \\ \hline O_{N_b x N_a} & B \end{array}\right]$$

where $O_{N_1 x N_2}$ = ~~$N_1 x N_1$~~ $N_1 x N_2$ zero matrix

67 Generalized Hyhbrid Walsh code matrices using functional combining with direct sum construction for $N=\sum_k N_k$

C_N = NxN generalized hybrid Walsh code matrix

$$C_N = f\left(C_0 \prod_{k>0} \oplus C_{N_k} , C_P \right)$$

where

$f(A,B)$ = functional combining operator of A,B

= the element-by-element covering of A with B for the elements of $A \neq 0$,

= the element-by-element sum of A and B for the elements of $A = 0$

C_P = NxN pseudo-orthogonal complex code matrix whose row code vectors are independent strips of PN codes for the real and imaginary components

It should be obvious to anyone skilled in the communications art that this example implementations of the generalized hybrid ~~hybrid complex~~ Walsh in equations **(18)** clearly define~~s~~ the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches. For example, the ~~Kronecker~~ tensor product matrices E_N and H_N can be replaced by functionals.

For cellular applications the transmitter description which includes equations **(18)** describes the transmission signal processing applicable to this invention for both the hub and user terminals in FIG. **1**, and the receiver corresponding to the decoding of equations **(18)** describes the corresponding receiving signal processing for the hub and user terminals in FIG. **1** for applicability to this invention.

~~Computationally efficient encoding and decoding of complex Walsh CDMA codes and hybrid complex Walsh CDMA codes:~~ It is well known that fast and efficient encoding and decoding algorithms

exist for the real Walsh CDMA codes. ~~These are documented in reference [6].~~ It is obvious that with suitable modifications these algorithms can be used to develop fast and efficient encoding and decoding algorithms for the ~~complex~~ hybrid Walsh CDMA codes since these complex codes have real and imaginary code vectors which are from the same set of real Walsh CDMA codes.

It is well known that the ~~Kronecker~~ tensor product construction involving DFT, H and real Walsh orthogonal code vectors have efficient encoding and decoding algorithms. It is obvious that with suitable modifications these algorithms can be used to develop fast and efficient encoding and decoding algorithms for the ~~Kronecker~~ tensor products of DFT, H and ~~complex~~ hybrid Walsh CDMA codes since these ~~complex~~ hybrid Walsh codes have real and imaginary code vectors which are from the same set of real Walsh CDMA codes. It is obvious that fast and efficient encoding and decoding algorithms exist for direct sum construction and functional combining.

Preferred embodiments in the previous description is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is ~~not~~ to be accorded the wider scope consistent with the principles and novel features disclosed herein.

~~REFERENCES:~~

~~[1] IEEE Communications magazine July 2000 Vol. 38 No. 7, Multiple Access for Broadband Networks"~~

~~[2] IEEE Personal Communications April 1998 Vol. 5 No. 2, "Third Generation Mobile Systems in Europe"~~

~~[3] TIA/EIA interim standard, TIA/EIA/IS-95-A, May 1995~~

~~[4] United States Patent 5,715,236 Feb. 3 1998, "System and method for generating signal waveforms in a CDMA cellular telephone system"~~

~~[5] United Statees Patent 5,943,361 Aug 24 1999, "System and method for generating signal waveforms in a CDMA cellular telephone system"~~

~~[6] K.G. Beauchamp's book "Walsh functions and their Applications", Academic Press 1975~~

DRAWINGS AND PERFORMANCE DATA

FIG. 1 CDMA Transmitter Block Diagram

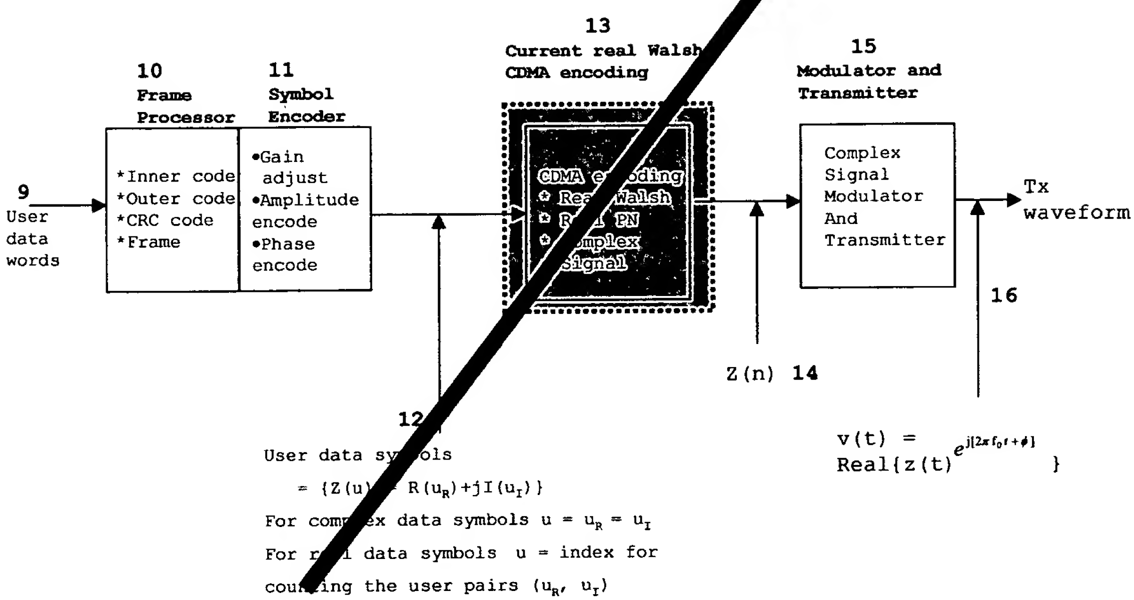
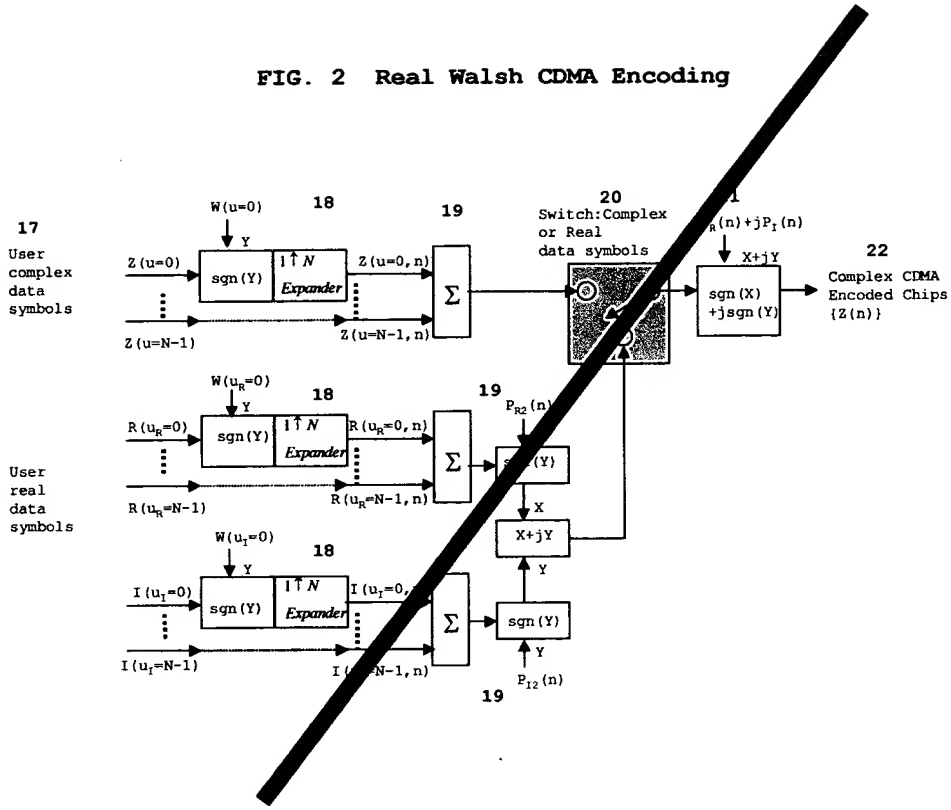


FIG. 2 Real Walsh CDMA Encoding



Y

FIG. 3 CDMA Receiver Block Diagram

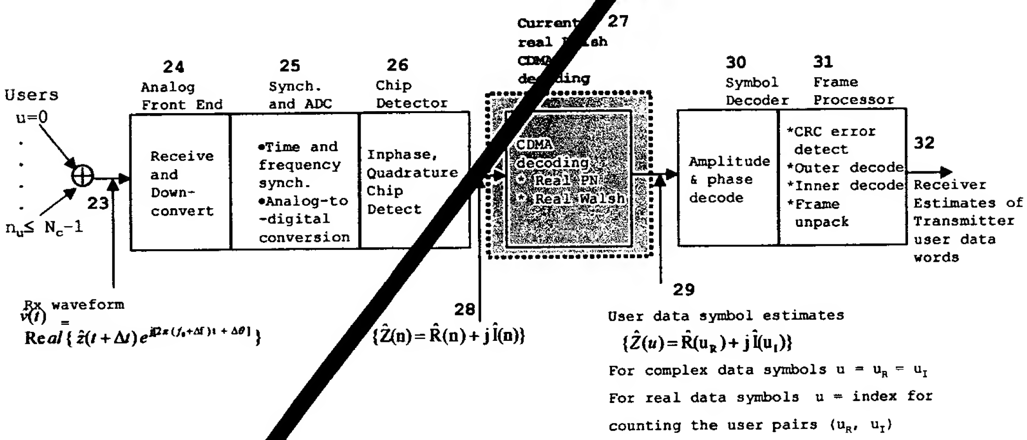


FIG. 4 Real Walsh CDMA Decoding

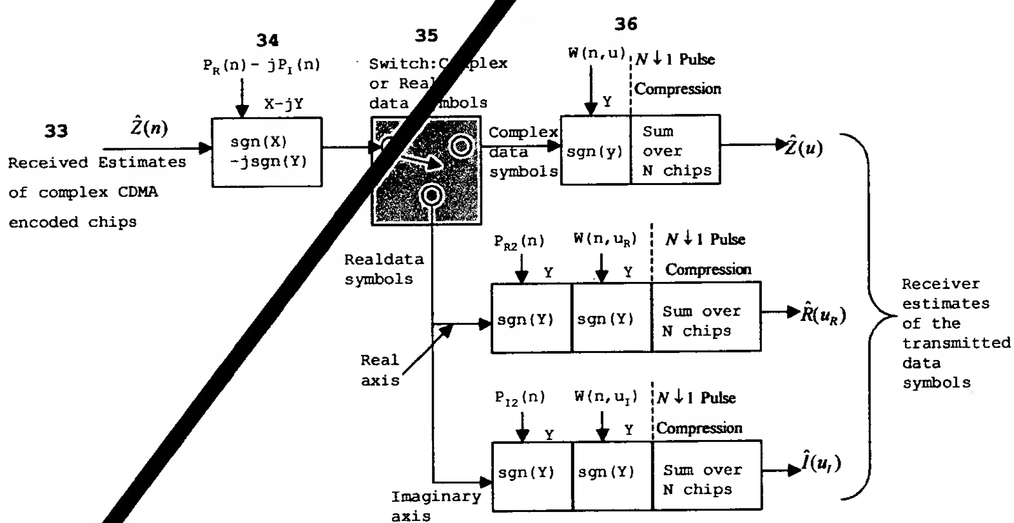


FIG. 5 Correlation of Fourier Codes with DFT Codes for N=32

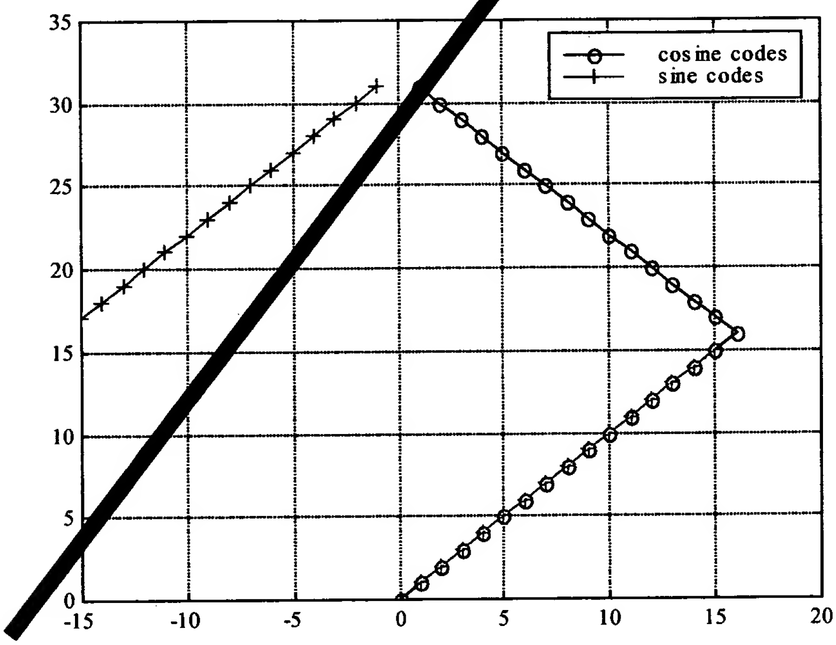


FIG. 6 Complex Walsh CDMA Encoding

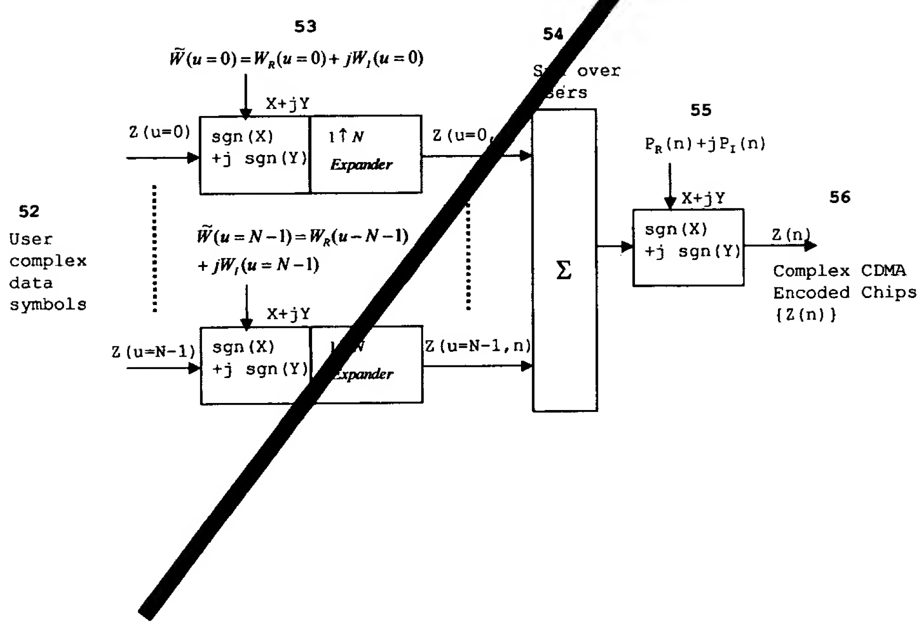
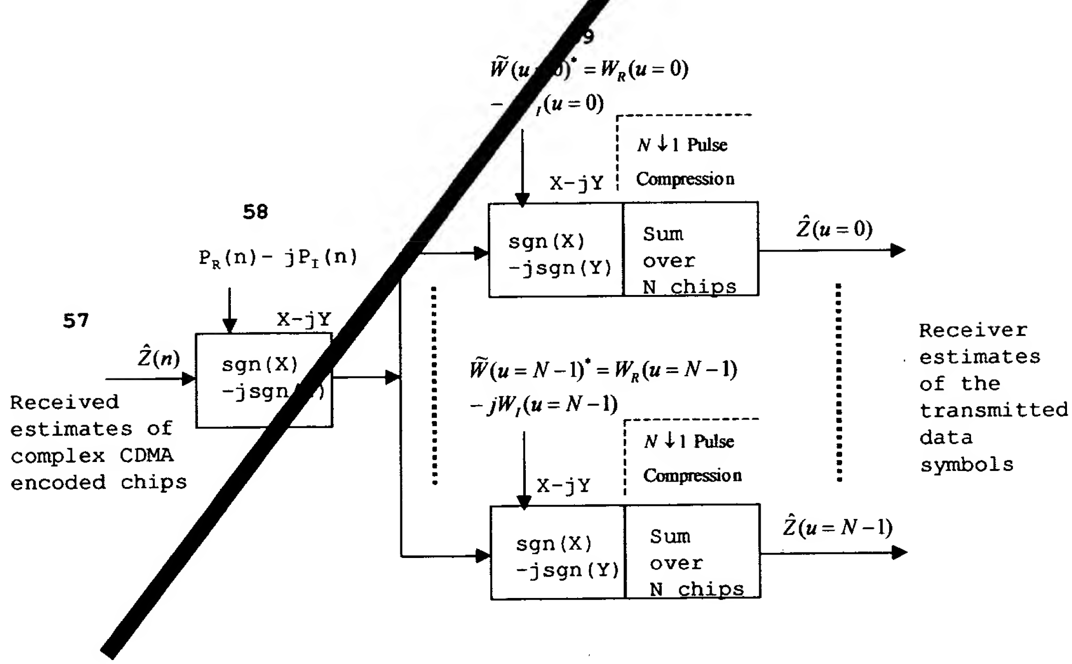


FIG. 7 Complex Walsh CDMA Decoding



APPLICATION NO. 09/826,117

TITLE OF INVENTION: Hyhrid Walsh Codes for CDMA

INVENTOR: Urbain A. von der Embse

Currently amended Claims

APPLICATION NO. 09/826,117

TITLE OF INVENTION: Hybrid Complex Walsh Codes for CDMA

INVENTOR: Urbain A. von der Embse

CLAIMS

WHAT IS CLAIMED IS:

Claim 1. (cancelled) ~~A means for the design of new complex Walsh orthogonal CDMA encoding and decoding over a frequency band with properties~~

~~provide a complex Walsh orthogonal code with the real component equal to the real Walsh orthogonal code~~

~~provide a complex Walsh orthogonal code with the imaginary component equal to a reordering of the real Walsh orthogonal code, which makes the complex Walsh orthogonal code the correct complex version of the real Walsh orthogonal code to within arbitrary angle rotations and scale factors~~

~~provide a complex Walsh orthogonal code which is in correspondence with the discrete Fourier transform (DFT) complex orthogonal codes wherein the correspondence is twofold: the sequency of the complex Walsh orthogonal codes is the average rate of rotation of the complex Walsh codes and corresponds to the frequency of the DFT codes with sequency as well as frequency increasing with the code numbering, and the second correspondence is between the even and odd complex Walsh code vectors and the cosine and sine DFT code vectors respectively~~

~~provide a complex Walsh orthogonal code which has the sign values +/-1 +/-j for the real and imaginary axes~~

~~provide a complex Walsh orthogonal code which has a fast decoding algorithm~~

~~provide a hybrid complex Walsh orthogonal code which can be constructed for a wide range of code lengths by combining the complex Walsh codes with DFT complex orthogonal codes~~

Claim 2. (cancelled) ~~A means for the design of new complex Walsh orthogonal CDMA codes with the properties~~

~~provide complex Walsh orthogonal CDMA codes which reduce to the real Walsh orthogonal CDMA codes upon removal of the complex code components~~

~~provide complex Walsh orthogonal CDMA codes which reduce to the real Walsh orthogonal CDMA codes upon removal of the real code components~~

~~provide a means for the computational efficient encoding and decoding of the complex Walsh orthogonal CDMA codes~~

Claim 3. (cancelled) ~~A means for the design of new complex Walsh orthogonal CDMA codes with the properties~~

~~provide the correct generalization of the real Walsh orthogonal CDMA codes to the complex Walsh orthogonal CDMA codes~~

~~provide a computationally efficient means to encode and decode the complex Walsh orthogonal CDMA codes~~

~~provide a means to extend the complex Walsh orthogonal CDMA codes to include the complex discrete Fourier transform (DFT) codes to allow greater flexibility in the choices for the code lengths~~

Claim 4. (cancelled) ~~A means for the design of hybrid complex Walsh orthogonal CDMA codes with the properties~~

~~provide a means to provide greater flexibility in the selection of the code length by combining the complex Walsh orthogonal CDMA codes with the complex DFT orthogonal CDMA codes~~

~~provide a Kronecker product means to combine the complex Walsh orthogonal CDMA codes with the complex DFT orthogonal CDMA codes~~

~~provide a direct sum means to combine the complex Walsh orthogonal CDMA codes with complex DFT orthogonal CDMA codes as well as other complex Walsh orthogonal CDMA codes~~

~~provide a functionality means to combine the complex Walsh orthogonal CDMA codes with the complex DFT orthogonal CDMA codes~~

Claim 5. (cancelled) ~~A means for the design of 4-phase Walsh orthogonal CDMA codes with the properties~~

~~provide 4-phase Walsh orthogonal CDMA codes which can be reduced to the 2-phase real Walsh orthogonal CDMA codes~~

~~provide 4-phase Walsh orthogonal CDMA codes which are the correct generalization of the 2-phase real Walsh orthogonal CDMA codes to 4-phases~~

~~provide hybrid Walsh orthogonal CDMA codes by combining the 4-phase Walsh orthogonal codes with the N-phase DFT codes with greater flexibility in the choice of the code length~~

Claim 6. (cancelled) ~~A means for the design of 4-phase Walsh orthogonal CDMA codes with the properties~~

~~provide 4-phase Walsh orthogonal CDMA codes in the code space~~ $\cancel{C^N}$ ~~which include the 2-phase real Walsh orthogonal CDMA codes in~~ $\cancel{R^N}$

~~provide 4-phase Walsh orthogonal CDMA codes which have computationally efficient encoding and decoding implementation algorithms~~

Claim 7. (currently amended) A ~~means~~ method for the ~~design and implementation of encoders and decoders for~~ generation of Hybrid Walsh complex orthogonal codes for CDMA and for the plurality of other applications, said method comprising:

means for deriving the inphase permutation of the Walsh or Hadamard codes which places them in the sequency correspondence which is the rate of phase rotation correspondence with the frequency and in the even code correspondence with the inphase component codes of the discrete Fourier transform (DFT),

means for deriving the quadrature permutation of the Walsh or Hadamard codes which places them in the sequency correspondence which is the rate of phase rotation correspondence with the frequency and in the odd code correspondence with the quadrature component codes of the DFT,

means for using the said inphase permutation to generate the inphase component codes of the said hybrid Walsh codes, and

means for using the said quadrature permutation to generate the quadrature component codes of the said hybrid Walsh codes.

~~CDMA channelization codes over a frequency band with properties~~

~~inphase (real) codes are equal to a lexicographic reordering permutation of the Walsh code~~

~~quadrature (imaginary) codes are equal to a lexicographic reordering permutation of the Walsh code~~

~~codes have a 1-to-1 sequency-frequency correspondence with the DFT codes~~

~~codes have 1-to-1 even-cosine and odd-sine correspondences with the DFT codes~~

~~codes take values {1+j, -1+j, -1-j, 1-j}~~

~~codes take values {1, j, -1, -j} with a (-45) rotation of axes and a renormalization~~

~~codes have fast encoding and fast decoding algorithms~~

~~encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes~~

~~decoders are implemented in CDMA receivers for representative embodiments as complex conjugate transpose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes~~

Claim 8. (currently amended) Said codes in Claim 7 have properties comprising:

code chips take values {1+j, -1+j, -1-j, 1-j} in the complex plane,

code chips with a renormalization and rotation of the code matrix take values {1, j, -1, -j} in the complex plane,

inphase axis codes of the said codes are reordered Walsh or Hadamard codes,

quadrature axis codes of the said codes are reordered Walsh or

Hadamard codes, and

~~A means for the design and implementation of encoders and decoders for generalized Hybrid Walsh complex orthogonal CDMA channelization codes over a frequency band with properties~~

~~codes can be constructed for a wide range of code lengths by combining with DFT and quasi-orthogonal PN codes using tensor product, direct product, and functional combining~~

~~codes can be constructed as tensor products with DFT codes and quasi-orthogonal PN codes and other codes~~

~~codes can be constructed as direct products with DFT codes and quasi-orthogonal PN codes and other codes and with functional combining~~

~~codes are complex valued~~

codes have fast encoding and fast decoding algorithms.

~~encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes~~

~~decoders are implemented in CDMA receivers for representative embodiments as complex conjugate transpose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes~~

Claim 9. (currently amended) A ~~means~~ method for the generation of gemeralized hybrid Walsh orthogonal codes for CDMA and for the plurality of other applications, from code sets which include hybrid Walsh, Hadamard, Walsh, discrete Fourier transform DFT, pseudo-noise PN, and the plurality of codes, said method comprising:

means for generating the said codes using tensor product techniques for codes selected from the plurality of code sets,

means for generating the said codes using direct product techniques for codes selected from the plurality of code sets, ~~the design and implementation of encoders and decoders for complex orthogonal CDMA channelization codes over a frequency band with properties~~

~~inphase (real) codes are equal to a reordering permutation of the Walsh code~~

means for generating the said codes using functional combining techniques for codes selected from the plurality of code sets, and

means for generating the said codes using combinations of tensor product techniques, direct product techniques, and functional combining techniques for codes selected from the plurality of code sets.

~~quadrature (imaginary) codes are equal to a reordering permutation of the Walsh code~~

~~codes are complex valued~~

~~codes have fast encoding and fast decoding algorithms~~

~~encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes~~

~~decoders are implemented in CDMA receivers for representative embodiments as complex conjugate tanspose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes~~

Claim 10. (currently amended) A ~~means~~ method for the generation of ~~design and implementation of encoders and decoders for generalized~~ complex orthogonal codes for CDMA and for the plurality of other applications, said method comprising:

means for deriving a inphase permutation of the Walsh or Hadamard codes or codes from the plurality of real codes,

means for deriving a quadrature permutation of the Walsh or Hadamard codes or codes from the plurality of real codes,

means for using the said inphase permutation to generate the inphase component codes of the said complex codes, and

means for using the said quadrature permutation to generate the quadrature component codes of the said complex codes.

~~CDMA channelization codes over a frequency band with properties~~

~~codes can be constructed for a wide range of code lengths by combining with DFT and quasi-orthogonal PN codes using tensor product, direct product, and functional combining~~

~~codes can be constructed as tensor products with DFT codes and quasi-orthogonal PN codes and other codes~~

~~codes can be constructed as direct products with DFT codes and quasi-orthogonal PN codes and other codes and with functional combining~~

~~codes are complex valued~~

~~codes have fast encoding and fast decoding algorithms~~

~~encoders are implemented in CDMA transmitters for representative embodiments as complex multiply channelization encoding of the inphase and quadrature data replacing the Walsh real multiply channelization encoding of the inphase and quadrature data, prior to covering by long and short complex PN codes~~

~~decoders are implemented in CDMA receivers for representative embodiments as complex conjugate transpose multiply decoding of the inphase and quadrature encoded data replacing the Walsh real multiply decoding of the inphase and quadrature encoded data, after decovering by short and long complex PN codes~~